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Kronauer, Richard E., Eskew, R.T., Jr. and Stromeyer, C.F. III

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When a suprathreshold luminance flash, presented as an increment on a larger background field, accompanies a circular equiluminant chromatic flash at the same spatial location, the chromatic threshold is reduced by about two-fold. This facilitation results from the clearly-visible edges of the luminance flash (the "pedestal") serving to demarcate the test region, segregating it from its surround. Signal detection experiments show that this facilitation does not occur because the contour reduces the spatio-temporal detection uncertainty of the observer. Partial and incomplete luminance contours produce partial facilitation. An illusory contour pattern can produce the full facilitation effect, measured with a forced-choice method. Recent experiments show that a thin luminance line which bisects the test region produces weak facilitation, the amount of which varies slightly with line length. This result poses a challenge to simple models of the facilitation mechanism, since the line does not demarcate two differently colored regions. The facilitation effect can be used as a rigorous means of probing the way in which low-level visual attributes (edges, color) interact at higher levels.

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John F Tangney	(202) 767-5021	NL

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The Effects of Luminance Boundaries on Color Perception

Submitted by:

Richard E. Kronauer

Professor Richard E. Kronauer
Harvard University
Division of Applied Sciences
Pierce Hall 324
Cambridge, MA 1990

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Dr. John F. Tangney
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Abstract

When a suprathreshold luminance flash, presented as an increment on a larger background field, accompanies a circular equiluminant chromatic flash at the same spatial location, the chromatic threshold is reduced by about two-fold. This facilitation results from the clearly-visible edges of the luminance flash (the "pedestal") serving to demarcate the test region, segregating it from its surround. Signal detection experiments show that this facilitation does not occur because the contour reduces the spatio-temporal detection uncertainty of the observer. Partial and incomplete luminance contours produce partial facilitation. An illusory contour pattern can produce the full facilitation effect, measured with a forced-choice method. Recent experiments show that a thin luminance line which bisects the test region produces weak facilitation, the amount of which varies slightly with line length. This result poses a challenge to simple models of the facilitation mechanism, since the line does not demarcate two differently colored regions. The facilitation effect can be used as a rigorous means of probing the way in which low-level visual attributes (edges, color) interact at higher levels.

Background

The goal of this research program is to understand better the ways in which edge or boundary information, carried primarily by the luminance system, interacts with chromatic information to determine the color of a region of the visual field. Recent physiological evidence (e.g., Maunsell & Newsome, 1987) indicates that different kinds of information are dealt with in separate, parallel processing streams in the brain. However, visual perception is generally unitary: we perceive objects, not disembodied properties such as luminance and color, suggesting that the distinct processing streams must interact at higher stages within the visual system. Our research is a psychophysical investigation of this interaction.

Review of Basic Findings

In our experiments to date, the stimulus is a 6 deg circular field of yellow light, which is completely uniform except for two fixation dots. During a trial, we can modulate the central 1 deg portion of the field in luminance, chromaticity, or both. When the field is modulated in both luminance and color, with enough luminance modulation to produce visible edges around the test region, threshold for detecting (and identifying the color of) the chromatic modulation is about half the threshold for detecting a purely equiluminant color modulation. Because the luminance modulation occurs in both intervals of the two-alternative forced choice (2AFC) task, and the chromatic modulation occurs "on top of" the luminance modulation in one interval, we refer to the luminance modulation as a "pedestal". In addition to halving threshold, the pedestal also reduces the slope of the psychometric function. Control experiments have demonstrated that these effects are the result of the contours of the pedestal; for instance, a thin ring which surrounds the test region produces identical effects. Further details of the method, and discussion of these and other results, are given in Cole, Stromeyer, and Kronauer (1990). Signal detection experiments (fully described in the Final Report for our last grant period) show that the facilitation is not simply due to the pedestal reducing the observer's detection uncertainty (Eskew et al., 1990).

New Results

We are performing a series of experiments to explore the effects of spatial variations in the luminance pedestal; some of these results were presented at ARVO last year, and more will be presented this year (abstracts attached). Our last Final Report included results of experiments in which a 360 deg ring pedestal and a 90 deg arc pedestal (radius matched to that of the test) were flashed at various locations relative to the test. Although facilitation falls off rapidly as the ring is shifted such that its edge lies within the test region, the arc produces substantial facilitation even when it lies near the center of the test.

The data of Fig.1 show how facilitation varies with the length of a 3 min wide, straight luminance line, flashed in the center of the test region as a pedestal. Short lines produce small amounts of facilitation, despite the fact that they do not demarcate any chromatic edge (the color is the same on both sides of the line); this is similar to the effect of the 90 deg arc when displaced into the test region. The appearance at threshold is of a fuzzy, chromatic oval, of approximately the same length as the line. The facilitation grows slightly with line length, reaching a maximum of less than half the effect obtainable with a 360 deg ring, and then declining for lines longer than about 0.5 deg. The effect of line length suggests that the ends of the line might have some effect upon the facilitating mechanism (see below).

In experiments which are still in progress, we are exploring the effects of removing the yellow annular region which normally surrounds the 1 deg test. With no surround, a ring or disk luminance pedestal masks chromatic detection, instead of facilitating it. Preliminary data suggest, however, that the centered line pedestal facilitates when there is no surround present, unlike the ring or disk. This result may indicate that the line somehow creates a comparison region <u>within</u> the test area; this comparison region might consist of the area surrounding the line, or just the area bounded by the edges of the line itself. Diffusion-based models of chromatic filling-in (e.g., Grossberg, 1987) can account for the facilitation by short lines only by assuming that the line is wide enough to generate a pair of diffusion barriers at each of its sides, forming a partition so that color signals do not diffuse. However, our experiments show that a short line of only ca. 1 min width (the narrowest line that can be produced on the retina) produced measurable facilitation, suggesting either that line width is not important (contradicting Grossberg's model) or that the mechanisms involved have a spatial scale in the hyperacuity range, which seems highly implausible.

Fig. 2 shows important data using some complex stimuli as luminance pedestals. An illusory contour-inducing stimulus, shown in B., produces the same facilitation as an actual ring (A.). When the "starburst" is completed through the test region (C.), no facilitation occurs. When the surrounding lines are elminated, leaving only a "starburst" which delimits the test region (D.), facilitation returns. These results show that a solid physical contour is not required to produce the facilitation. However, they do not imply that an illusory contour can produce the facilitation, since observers never report seeing strong illusory contours generated by these figures when the figures are presented in 200 ms flashes. This observation is confirmed with stimulus E.; here a dotted line produces the full facilitation even though it never produces a good illusory contour. What seems to matter is that the test region is demarcated; whether or not a continuous contour is seen around the test is not important. An extreme example of this is shown in Fig. 3, in which one, two, or three small dots were placed along the circumference of the test area. The three dots (separated by 120 deg) produce nearly the full facilitation. It is not yet clear how to reconcile this "demarcation" view with the results of Fig. 1, in which the luminance line does not demarcate differently-colored regions.

These results show that luminance contours which have terminators (the line segments, arcs, dots, illusory contour stimulus) may interact with chromatic information in ways which are different from the interactions produced by closed contours (the disk and ring pedestals used in our earlier work). Our current modeling efforts are directed at understanding how isolated pieces of contour can facilitate chromatic detection.

Other work under joint AFOSR and NIH sponsorship includes exciting new results measuring cone input signals to motion detectors. Coincident red and green, 1 cpd, vertical sine gratings (3.5° dia) are presented on a 4000 td, foveal yellow field (4.2° dia). At each of a wide range of velocities (1-21 deg/sec: 1-21 Hz), the two gratings move together either left or right, and the 2AFC threshold is determined for direction identification. Thresholds are measured for many amplitude ratios of the red and green gratings to obtain a complete detection contour, which indicates how the M and L contrast signals are combined for motion detection.

Our original, simple hypothesis was that direction thresholds would readily reveal a 'luminance' mechanism, most sensitive to motion, indicated by a straight detection contour of negative slope (M and L signals linearly add in-phase). Our surprising results refute this hypothesis for velocities up to 9 deg/sec, because a more sensitive spectrally-opponent motion detector intervenes. Fig. 4, crosses, shows direction thresholds of 1 Hz (1 deg/sec) gratings (each cross is a threshold for a given amplitude ratio of red-to-green gratings, with the companion point, mirror symmetric about the origin, not shown). Luminance detection is revealed by the single point on the +45° axis, whereas the other points, fitted by a line of slope 1.05, reveal a more sensitive spectrally-opponent motion detector (which does not appear to signal hue). The contour of the latter mechanism becomes steeper as temporal frequency is increased (1-9 Hz) and is almost vertical at 9 Hz (results are shown for an intermediate temporal frequency of 4 Hz, Fig. 5): the spectrally-opponent motion detector is L cone dominated and is more sensitive than the luminance mechanism up to 9 Hz; the luminance mechanism is more sensitive only above 16 Hz.

Future Plans

Our long-overdue video hardware, the Psychophysics Display Interface (PDI), has finally been delivered. The Barco color monitor, Macintosh II computer, and other hardware we will use with the PDI are all in hand. We will finish our software development and begin running many of our facilitation experiments on the video system. This system, which permits extremely precise color control, will provide the flexibility we need to produce complex spatial test patterns, and permit us to understand better the mechanisms responsible for facilitation.

Quite soon we expect to begin using test spots of 20 min and smaller, instead of the 1 deg spot we have always employed, to repeat a number of key facilitation results. Our expectation is that the facilitation will be substantially larger with the smaller spot, and will permit easier measurement of the effects of spatial variations in the pedestal.

Participating Professionals

Rhea T. Eskew, Jr., Ph.D.
Charles F. Stromeyer, III, Ph.D.
Richard E. Kronauer, Ph.D., Principal Investigator

Publications and Publications in Progress

Cole, G.R., Stromeyer, C.F. III, & Kronauer, R.E. (1990) Visual interactions with luminance and chromatic stimuli. Journal of the Optical Society of America, A7, 128-140. (attached)

Eskew, R.T., Jr., Stromeyer, C.F. III, & Kronauer, R.E. (1990) An illusory-contour luminance pattern can facilitate equiluminant chromatic discrimination. Investigative Ophthalmology and Visual Science(Suppl.), 31, 264. (attached)

Eskew, R.T., Jr., Stromeyer, C.F. III, & Kronauer, R.E. (1990) The time course of the facilitation of chromatic detection by luminance contours. Manuscript in preparaton.

Eskew, R.T., Jr., Stromeyer, C.F. III, & Kronauer, R.E. (1990) The temporal impulse response function of the red-green chromatic mechanism. Manuscript in preparation.

Eskew, R.T., Jr., Stromeyer, C.F. III, Picotte, C.J., & Kronauer, R.E. (1990) Reduction of detection uncertainty does not explain the facilitation of chromatic detection by luminance contours. Journal of the Optical Society of America, submitted.

Stromeyer, C.F. III, Eskew, R.T., Jr., & Kronauer, R.E. (1989) Chromatic facilitation by a luminance edge. Investigative Ophthalmology and Visual Science (Suppl.), 30, 220. (attached)

Stromeyer, C.F. III, Eskew, R.T., Jr. & Kronauer, R.E. (1990) The most sensitive motion detectors in humans are spectrally-opponent. Investigative Ophthalmology and Visual Science (Suppl.) 31, 1182.(attached)

Stromeyer, C.F. III, Eskew, R.T., Jr., Kronauer, R.E., & Spillmann, L. (1990) Temporal phase response of the short-wave cone signal for color and luminance. Vision Research, submitted.

Interactions

Association for Research in Vision and Ophthalmology, 1989 annual meeting, Sarasota, FLA. Eskew and Stromeyer attended, and made two presentations. Abstracts attached.

SPSE meeting, 1989, Boston. Kronauer attended, and presented an invited talk on contour-chromatic detection interactions. Discussion included discussions with Professor Grossberg about how his model might account for our line-length data (Fig. 1).

Center for Adaptive Systems, Boston University. Eskew met with Drs. Grossberg and Mingolla, to informally discuss data (including the line-length data, Fig. 1) and applications of their model.

Rowland Institute Mini-Conference on Isoluminance, Sept. 1989. Eskew and Stromeyer attended, and presented results on contour-chromatic interactions. Attendees included physiologists and psychophysicists with interests in equiluminant phenomena.

Neurosciences Institute (Rockefeller University) Conference on Color Spaces. Eskew and Stromeyer attended, and discussed the Weberian cone space representation of chromatic stimuli that we use. Attendees were physiologists and psychophysicists seeking better ways to represent and understand the effects of color. A second, follow-up meeting is being planned, to take place in Cambridge under the sponsorship of the Rowland Institute.

References

Grossberg, S. (1987) Cortical dynamics of three-dimensional form, color, and brightness perception: I. Monocular theory. Perception & Psychophysics, 41, 87-116.

Maunsell, J.H.R., & Newsome, W.T. (1987) Visual processing in monkey extrastriate cortex. Annual Review of Neuroscience, 10, 363-401.

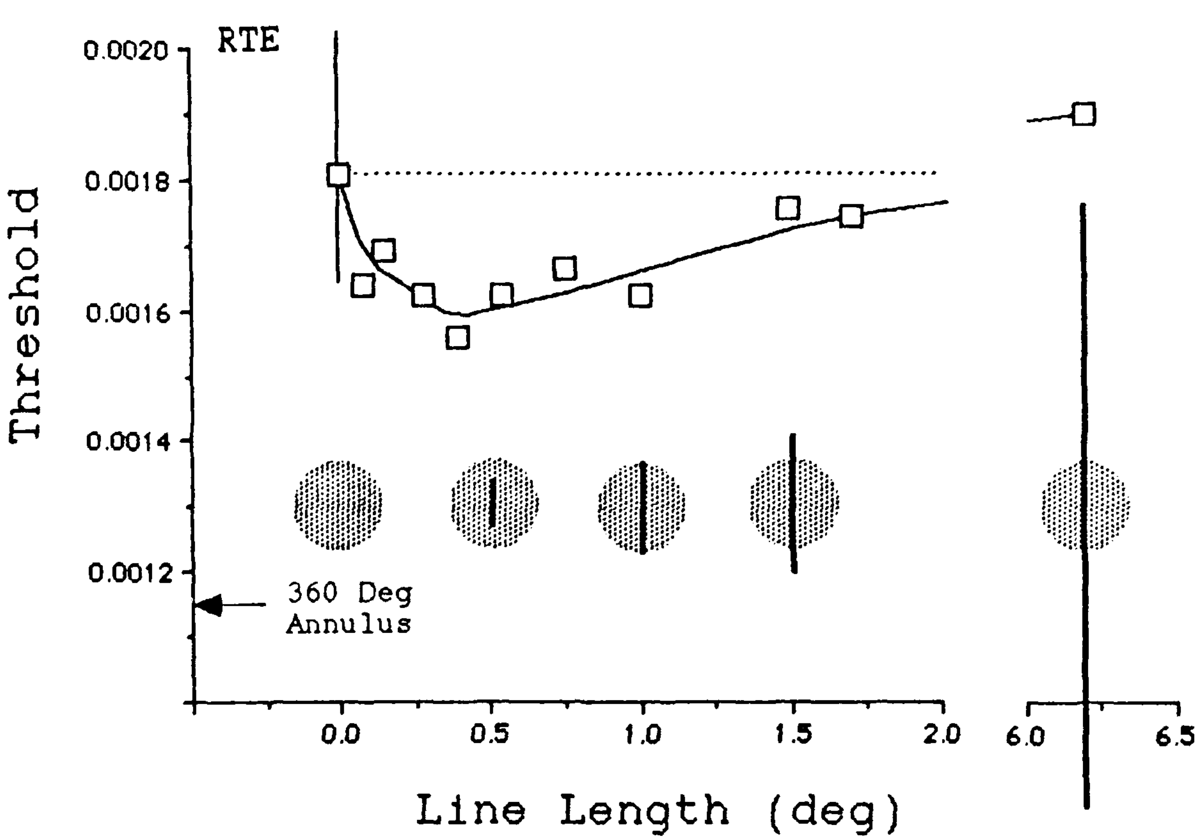

Fig. 1 Chromatic detection threshold as a function of the length of a 3 min wide luminance line, which was flashed in the center of the test region as a pedestal. Maximum facilitation is obtained for lines of about 0.5 deg length. Threshold for the ring pedestal is indicated by the arrow.

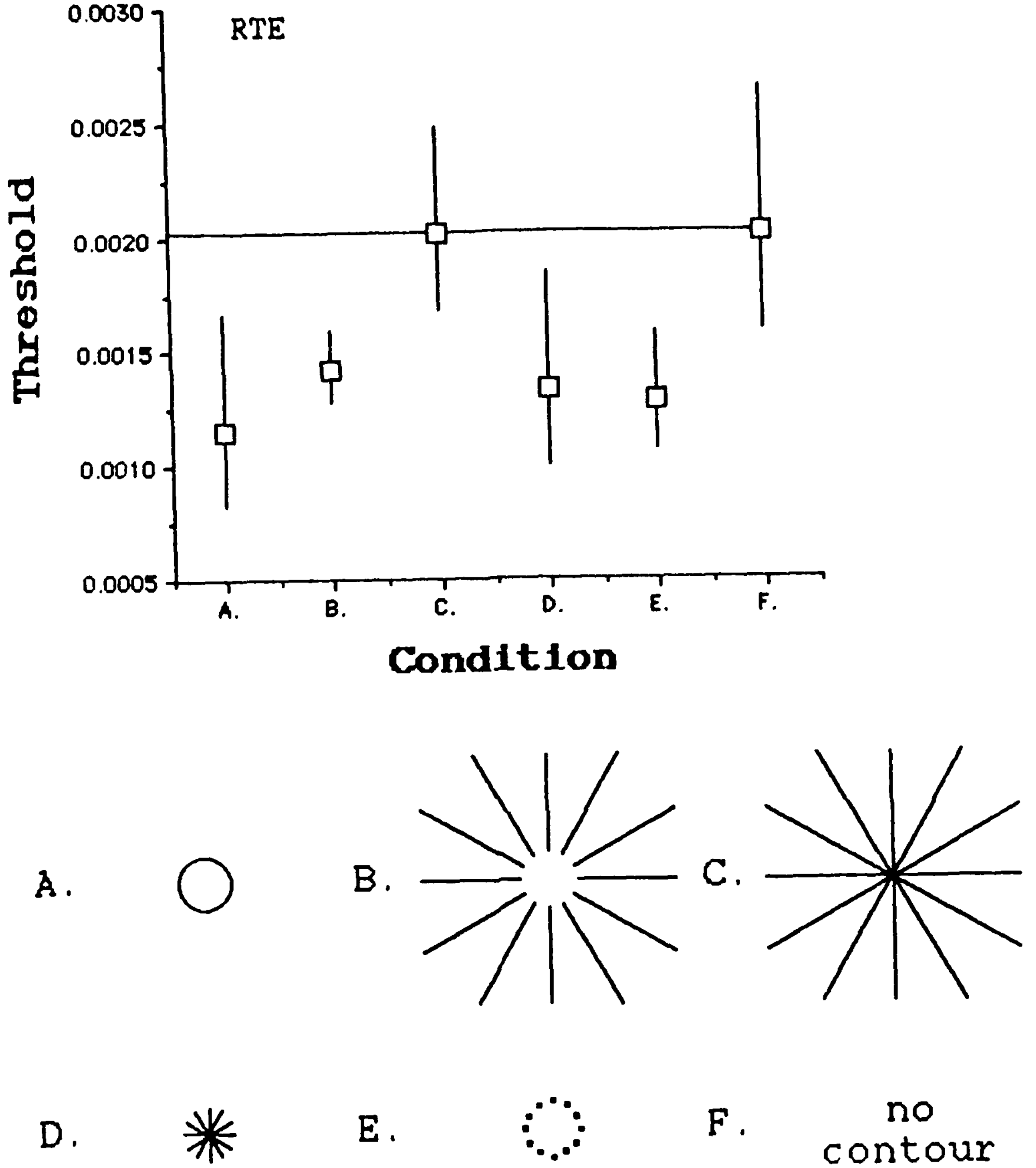

Fig. 2. Effects of various spatial configurations of the luminance pedestal. Chromatic threshold for one observer is plotted for each of the luminance pedestals shown in the bottom part of the figure. The four stimuli on the bottom left (A, B, D, and E) facilitate about equally well, while the two on the right (C and F) do not. A pedestal which segments the test region from the surrounding area produces facilitation.

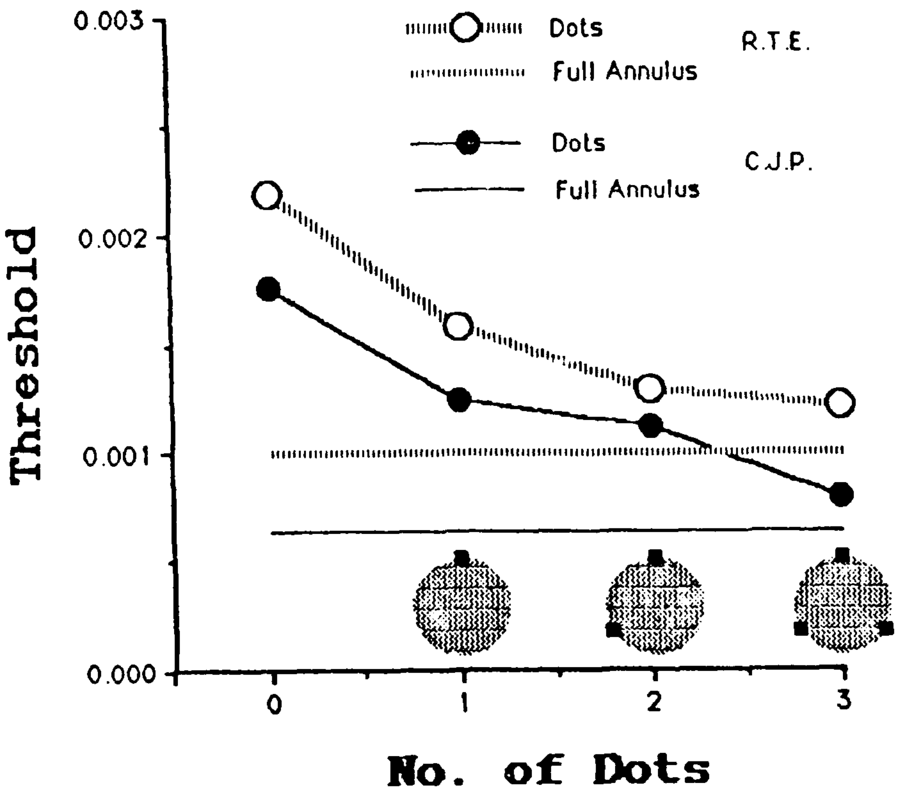

Fig. 3. Chromatic detection threshold as a function of the number of luminance "dots" arrayed around the test circumference. Data from two observers are plotted; the horizontal lines represent threshold for a solid 360 deg ring for each observer separately. Even one dot has an effect, and three dots produce almost the maximum facilitation.

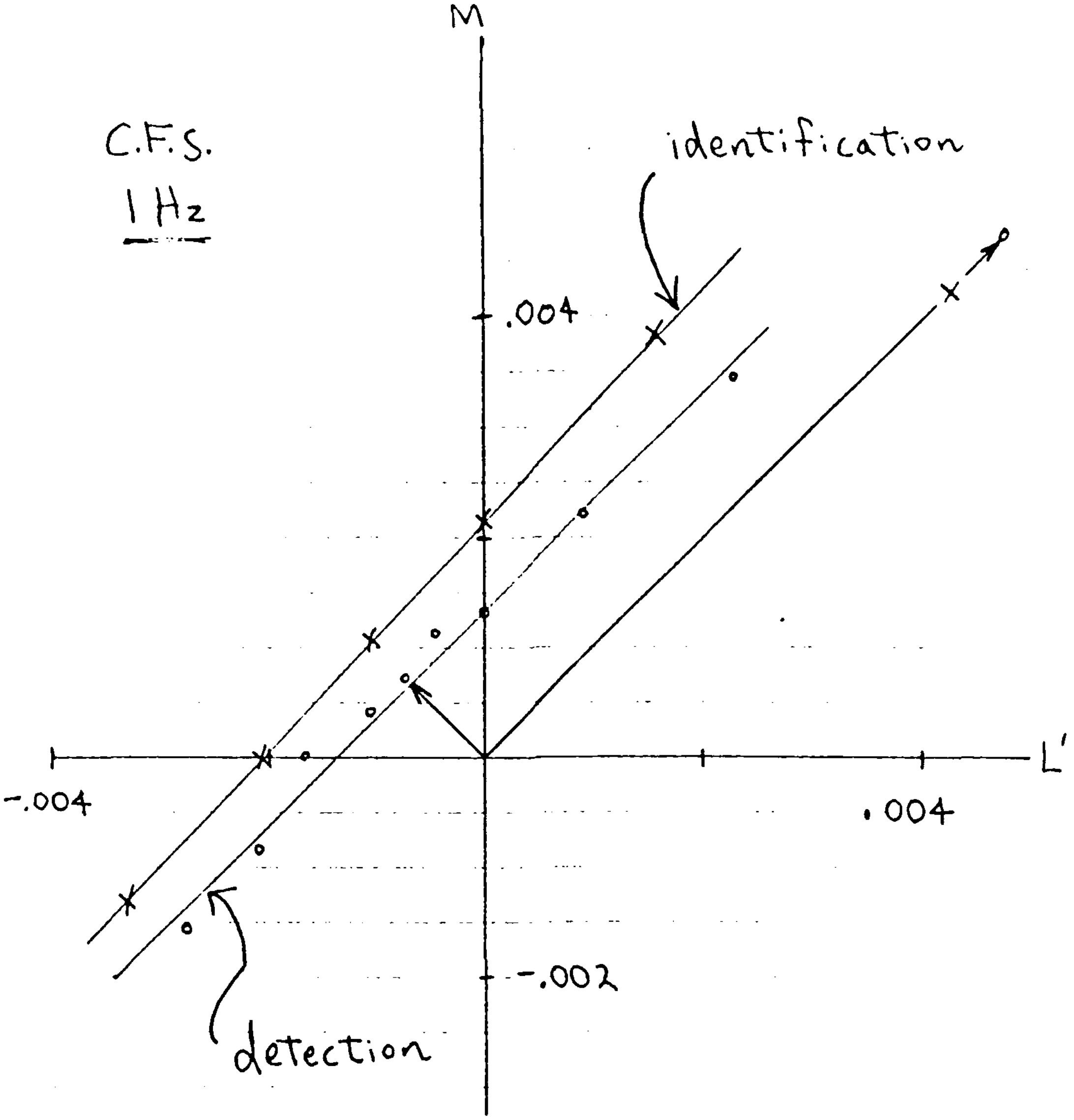

Fig. 4. Threshold (mere detection--circles) and (direction identification, left vs. right--crosses) for a vertical 1 cpd grating moving at 1 deg/sec. The grating is a summed red+green pair of gratings: the amplitude ratio of the pair determines the L and M cone contrasts of the grating, plotted here in the cone contrast coordinates L',M'. The long 'detection' contour represents the red-green chromatic mechanism: to see motion the grating contrast must be raised to the 'identification' contour. The observer is more sensitive to the motion produced by the chromatic grating (-45° diagonal) than the luminance grating (+45° diagonal).

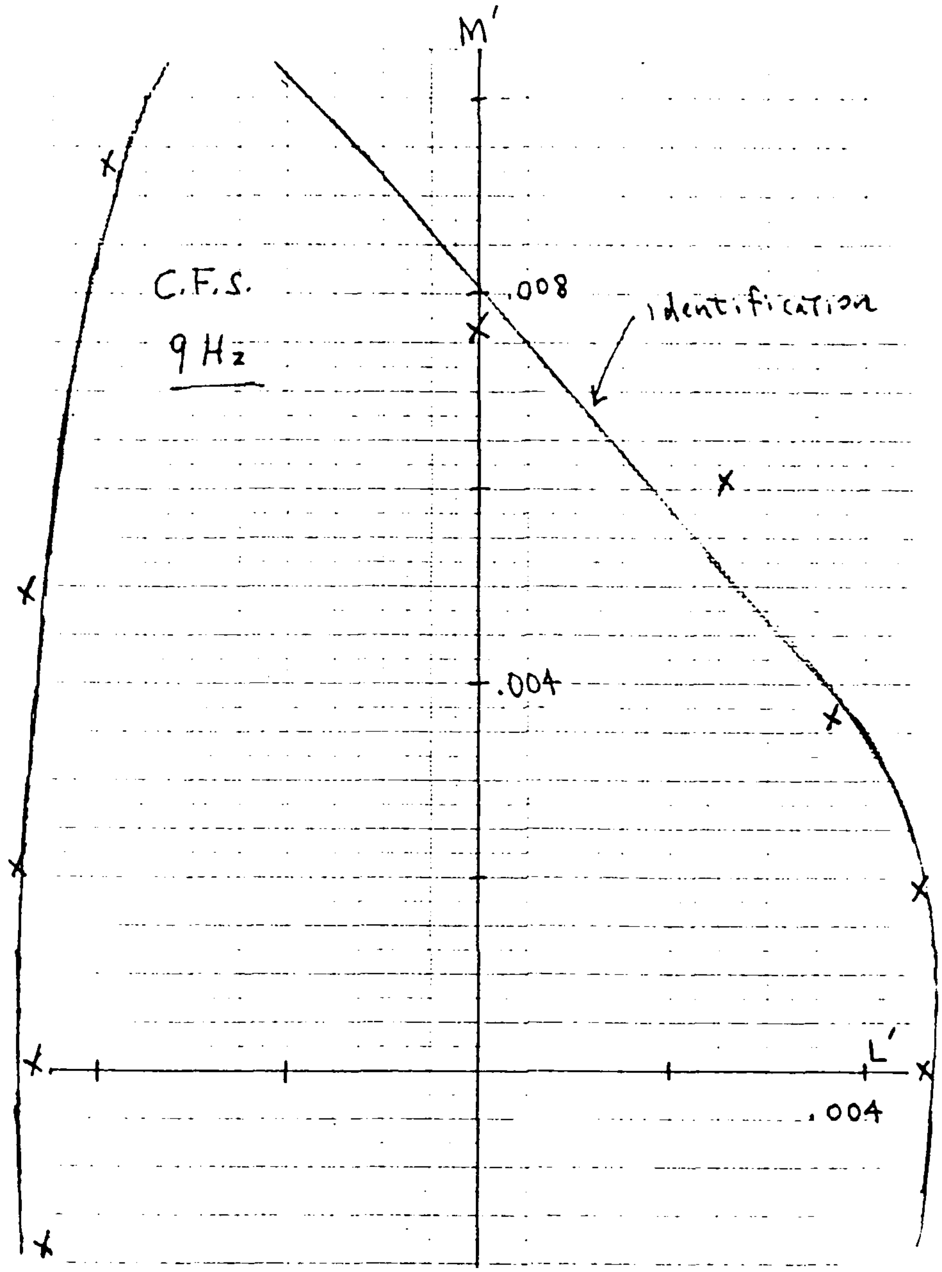

Fig. 5   Similar to Fig. 4, but showing direction thresholds for the grating moving at 9 Hz. The straight contour of negative slope represents the luminance mechanism, whilst the approximately vertical contours represent the more sensitive L-cone dominated spectrally-opponent mechanism.